

# Energy Storage for Hybrid Military Vehicles

Ghassan Y. Khalil

## Abstract

The benefits of hybrid electric vehicles have been recognized by the US Army and other military services. As a consequence, hybrid vehicles are being considered as future combat and tactical platforms. In order to achieve this objective, a number of integration challenges need to be overcome for every component system within the vehicle. Energy storage is one of the major systems of concern in the hybrid electric application. While a number of energy storage devices and concepts have been considered, the focus of this paper is on the rechargeable battery systems, their suitability, challenges and limitations. This paper discusses the integration and application of energy storage in hybrid vehicles. It also explores the challenges and the various solutions that have been proposed to obtain a functional, reliable and safe energy storage in future All Electric Combat Vehicles (AECV).

**Keywords:** battery, HEV, energy storage, battery management

## Introduction

The potential benefits of hybrid electric vehicles for military applications have been recognized by the US Army as well as other military services. Hybrid electric vehicles are being conceived and prototyped for future combat and tactical platforms. To achieve an all Electric Combat Vehicle (AECV), integration challenges have to be overcome for every system in the new vehicle. Energy storage is one of the major systems in a hybrid electric application. While many energy storage devices have been considered, the objective here is to address the rechargeable battery systems in terms of their suitability, challenges and limitations.

Unlike present commercial vehicle designs, the energy storage requirements in military vehicles extend beyond load leveling of the main voltage bus. In military vehicles, energy storage is required for silent watch and silent mobility applications. These vehicle operations have to be conducted independently of an internal combustion power source. Both high power and high energy capacity are critical for mission implementation and must be delivered from the battery pack. Also required are the related cooling and electronic controls that must be included and must fall within the constraints of very limited space and weight vehicle requirements.

In addition, the battery voltage is normally limited to 2-4 volts at the cell level, up to 50 volts at the module level and 300 volts at the pack level. Thus in most cases, a bidirectional dc-dc converter is required between the battery and the bus to maintain safe and reliable operation.

Figure 1 shows one proposed arrangement for achieving the vehicle energy storage objective. Although less than optimal in terms of energy density with respect to packing efficiency, the use of cylindrical cells provides ready made channels for air cooling the battery pack.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>11 MAR 2005</b>		2. REPORT TYPE		3. DATES COVERED -	
4. TITLE AND SUBTITLE <b>ENERGY STORAGE FOR HYBRID MILITARY VEHICLES</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) <b>GHASSAN KHALIL</b>				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>US ARMY RESEARCH DEVELOPMENT AND ENGINEERING CENTER, AMSRD-TAR-R/MA 121,6501 EAST 11 MILE RD, WARREN, MI, 48397-5000</b>				8. PERFORMING ORGANIZATION REPORT NUMBER <b>14744</b>	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <b>The benefits of hybrid electric vehicles have been recognized by the US Army and other military services. As a consequence, hybrid vehicles are being considered as future combat and tactical platforms. In order to achieve this objective, a number of integration challenges need to be overcome for every component system within the vehicle. Energy storage is one of the major systems of concern in the hybrid electric application. While a number of energy storage devices and concepts have been considered, the focus of this paper is on the rechargeable battery systems, their suitability, challenges and limitations. This paper discusses the integration and application of energy storage in hybrid vehicles. It also explores the challenges and the various solutions that have been proposed to obtain a functional, reliable and safe energy storage in future All Electric Combat Vehicles (AECV).</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES <b>4</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			



Figure 1. **SAFT CHPS Battery**  
 281V MAX, (288 Cells/Battery)  
 Air Cooled, ~270KG (with fans, insulation, heat exchanger, electronics)  
 15.8KWH (~63.2Wh/kg)  
 18Sec: 154KW (~615W/kg)

## Integration of a DC-DC converter for energy storage in HEVs

Integrating an energy storage system and choosing an architecture solution that best fits the application requires extensive concept design and evaluation in the case of hybrid electric propulsion. Hybrid electric vehicles are being designed to use a high-voltage dc bus (> 300Vdc). To supply high power to electrical subsystems normally requires variable-voltage bi-directional dc-dc converters to interface between the main storage battery pack and the high-voltage bus.

Possible architectures include (a) direct battery pack connection to the high voltage bus, (b) a single bi-directional dc-dc converter with a high voltage battery pack and (c) multiple sets of low voltage battery modules each in series with a low-voltage, high current dc-dc converter with the entire arrangement connected in a parallel configuration to the high voltage bus. There are pros and cons in each option in terms of redundancy, reliability, safety and cost. Use of a dc-dc converter has a potential to improve the overall efficiency, reliability, and safety for a compact system as compared to the direct connection scenario. DC-DC converters must be optimized for high power density. An optimal thermal management system is required since the proposed DC-DC converter designs incorporate recent advances in semiconductor technology that accommodate the increases in power density and efficiency. Achieving a high power density in DC-DC converters creates some technical issues that must be taken into account. These include materials stability at the high operating temperatures and electromagnetic compatibility (EMC) considerations.

## Battery Pack Reliability

The estimated probability for fabricating a functional battery pack, where the cells are configured in a series string, is the product of the probabilities that any single cell is functional. Certain inferences arise from this observation. The battery pack reliability decreases with the number of

cells connected in series. Also, the battery pack behavior is controlled largely by the poorest performing cell in a string.

From this, it follows that the reliability of the battery is improved if the number of cells connected in series is reduced. That is, the cell string voltage is kept low. Doing this implies that the dc to dc conversion requires a substantial step up of the string voltage.

Parallel strings could be used to increase the total energy stored by installing additional strings. By switching failed strings out of the power source increases the battery pack reliability. Also, the power demand on any particular string configured in a parallel arrangement of strings has a reduced current demand. Although there is a need for more DC/DC converters, their individual current handling capability is reduced. It is evident that additional control circuitry would be required to support this architecture.

## **Battery Heating on Overcharge**

During battery discharge, the heat generated is the sum of the Joule and enthalpic (chemical) heating effects. Conversely, during battery charging, the heat generated is the Joule minus the enthalpic heating. If the conditions are carefully selected, one can observe a net battery cooling during charging.

However, an interesting phenomenon takes place during overcharge. Those cells designed as sealed recombinant systems develop a significant heat production on overcharge. Flooded designs do not exhibit this effect. The reason is that the electrical energy stored in the cells generates energetic reaction products as a consequence of the electrochemical reaction. This is an energy absorbing process. The gasses produced during overcharge are then vented into the environment. Since the sealed cells undergo a closed recombination cycle, i.e., no material is exchanged with the environment, the rate of heat generated is determined by the power input to the cell. It will be recalled that the power dissipation is the current passing through the cell multiplied by the voltage gradient which is the cell voltage. Essentially, the cell is behaving in the manner of a heat dissipating resistor.

In this connection, the thermal runaway (TR) phenomenon has been often observed in sealed cell designs and this raises a potential problem in battery applications incorporating sealed batteries. As a practical matter, sealed batteries are preferred over the classical flooded designs.

It is not efficient to design around the worst case scenario, i.e., anticipating the thermal runaway effect. It is wiser to detect its onset and shut down the charging process. An alternative approach is to develop an understanding of the TR process and, perhaps, develop a method for effectively controlling or eliminating it altogether.

In the case of lithium batteries, the thermal runaway effect is compounded by the potential for inducing the oxidation of the electrolyte solvent. A number of alternatives are being considered to minimize or eliminate this potential failure mode. This particular problem is not considered to be significant in the smaller lithium ion cells. However, the larger cells have a mass to surface area ratio that limits the rate of heat transfer. The consequence of this is that during heat generation, higher internal temperatures are developed to dissipate the heat produced. This heat rejection issue is a matter of on going investigation.

## **The Challenge**

Several types of batteries are being considered to meet the above described technical challenges in a vehicle energy storage system. The favored set of battery chemistries in the United States in the order of decreasing interest consists of rechargeable lithium, nickel-zinc, nickel metal-hydride and lead acid. Other types of batteries are also being studied as future candidates. Programs are currently underway addressing investigations into failure modes, increasing energy density, reducing cost and improving reliability.

For every problem arising from the battery management there are solutions. However, at the system level a particular solution sometimes uncovers new problems or becomes the cause of other issues that need to be subsequently addressed. These unintended consequences are to be expected when dealing with the integration of complex systems.

Another consideration that will eventually have to be addressed is the operation and maintenance cost connected with hybrid electric power sources. Battery pack maintenance must be performed at the proper level of competence in the field. Maintenance procedures for dealing with battery pack replacement, cell replacement and refurbishment still need to be worked out.

## **Summary**

Future Combat Vehicles in the United States and other nations are expected to include hybrid Electric platforms not because of single well identified benefit; but because of a combination of payoffs that has the potential to provide the soldier expanded capabilities in both peace time and war time scenarios. The application of hybrid electric vehicles and particularly All Electric Combat Vehicles (AECV) require complex systems among which the energy storage system is quite challenging. Although, the development and demonstration of advanced battery chemistry has been successfully demonstrated in the lab and on commercial vehicles, the demand of the power and energy for military missions and the integration of a functional, reliable, affordable and safe system within an integrated power pack require intensive investigation and maturation before successful fielding of AECV.

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Ghassan Y. Khalil was graduated with a B.Sc. and M.Sc. in Mechanical Engineering from Wayne State University, Detroit, Michigan. He has 10 years experience in the auto Industry: Ford Motor Co. covering automotive power train design and test and evaluation. Following that he has served for 20 years at the US Army Tank Automotive and Armaments Command Research Center (TARDEC). He is currently the Team leader of the Hybrid Electric Research Program. The team mission is to field hybrid electric combat vehicles.